Electromagnetic emission from hot medium measured by the PHENIX experiment at RHIC

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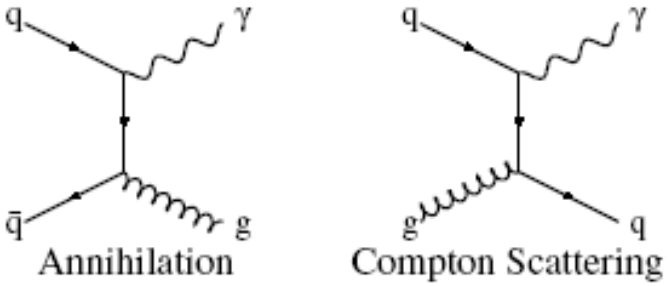
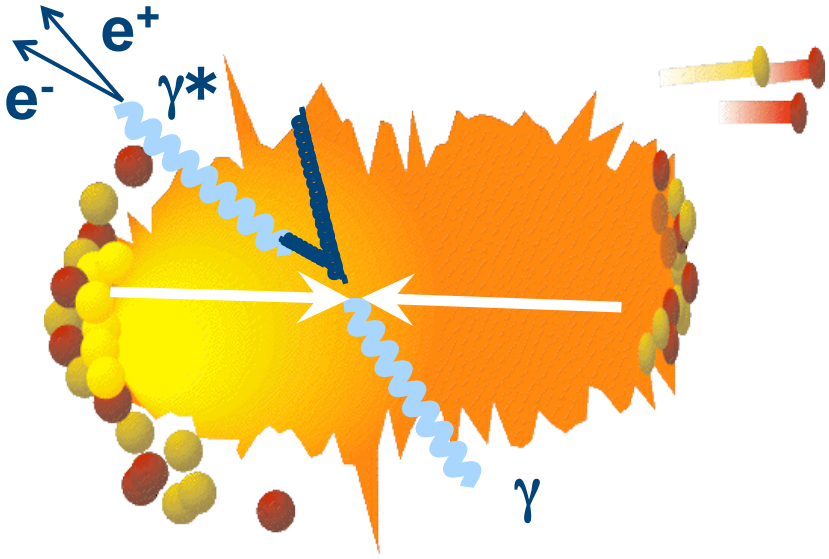
Electromagnetic probe (photon) basics

- Production Process
  - Compton and annihilation (LO, direct)
  - Fragmentation (NLO)
  - Escape the system unscathed

- Carry dynamical information of the state
  - Temperature, Degrees of freedom
    - Immune from hadronization (fragmentation) process at leading order
  - Initial state nuclear effect
    - Cronin effect (k_T broardening)

Photon Production: **Yield** $\propto \alpha\alpha_s$

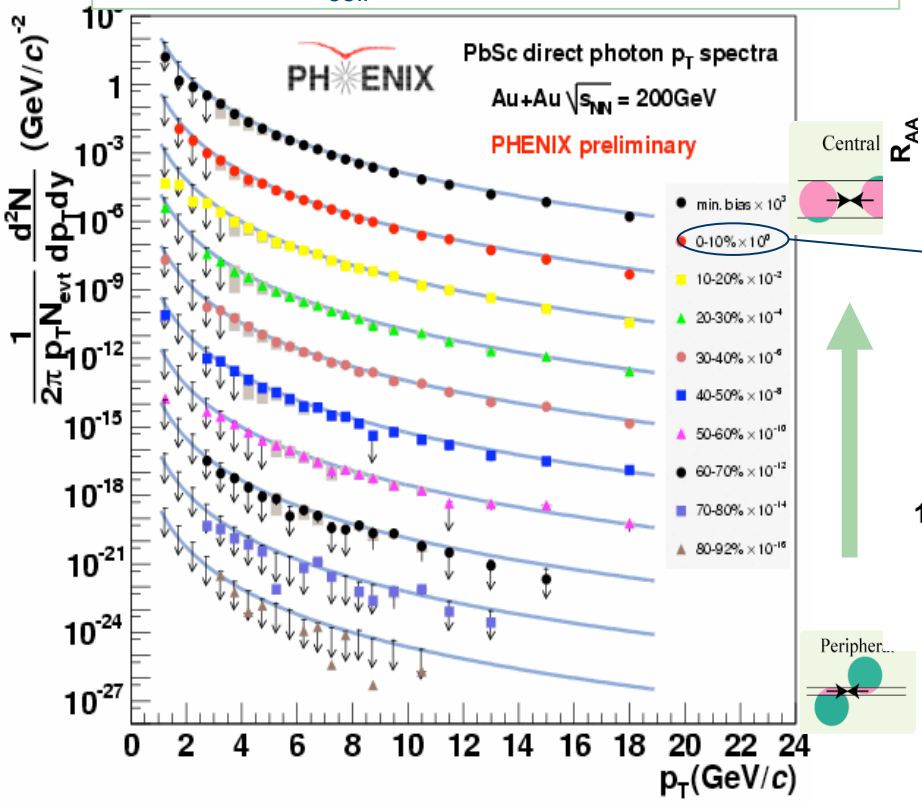


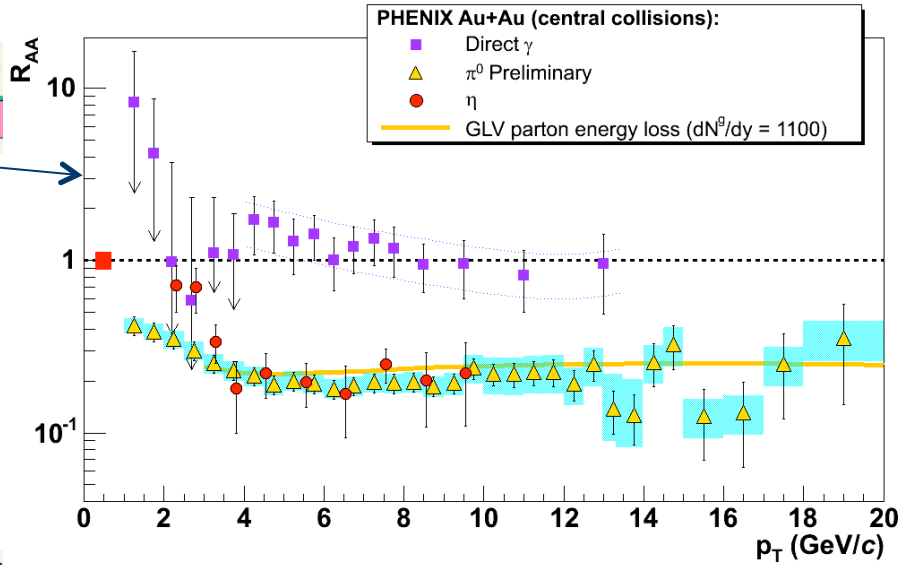


Hard scattering γ_{dir} in Au+Au (high p_T)

- Au+Au = p+p x T_{AB} holds – pQCD factorization works
- NLO pQCD works. → Non-pert. QCD may work in Au+Au system

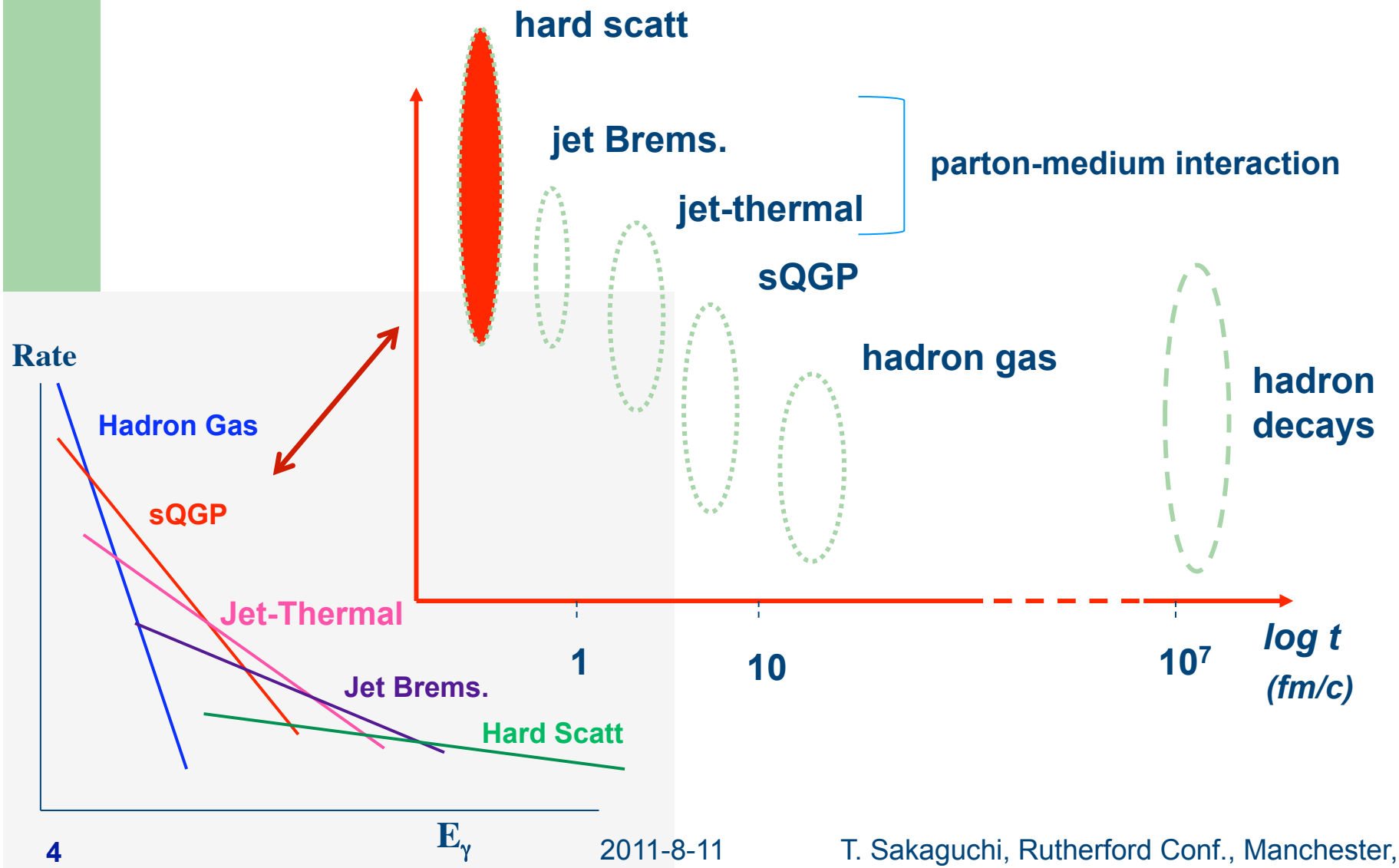
Blue line: N_{coll} scaled p+p cross-section



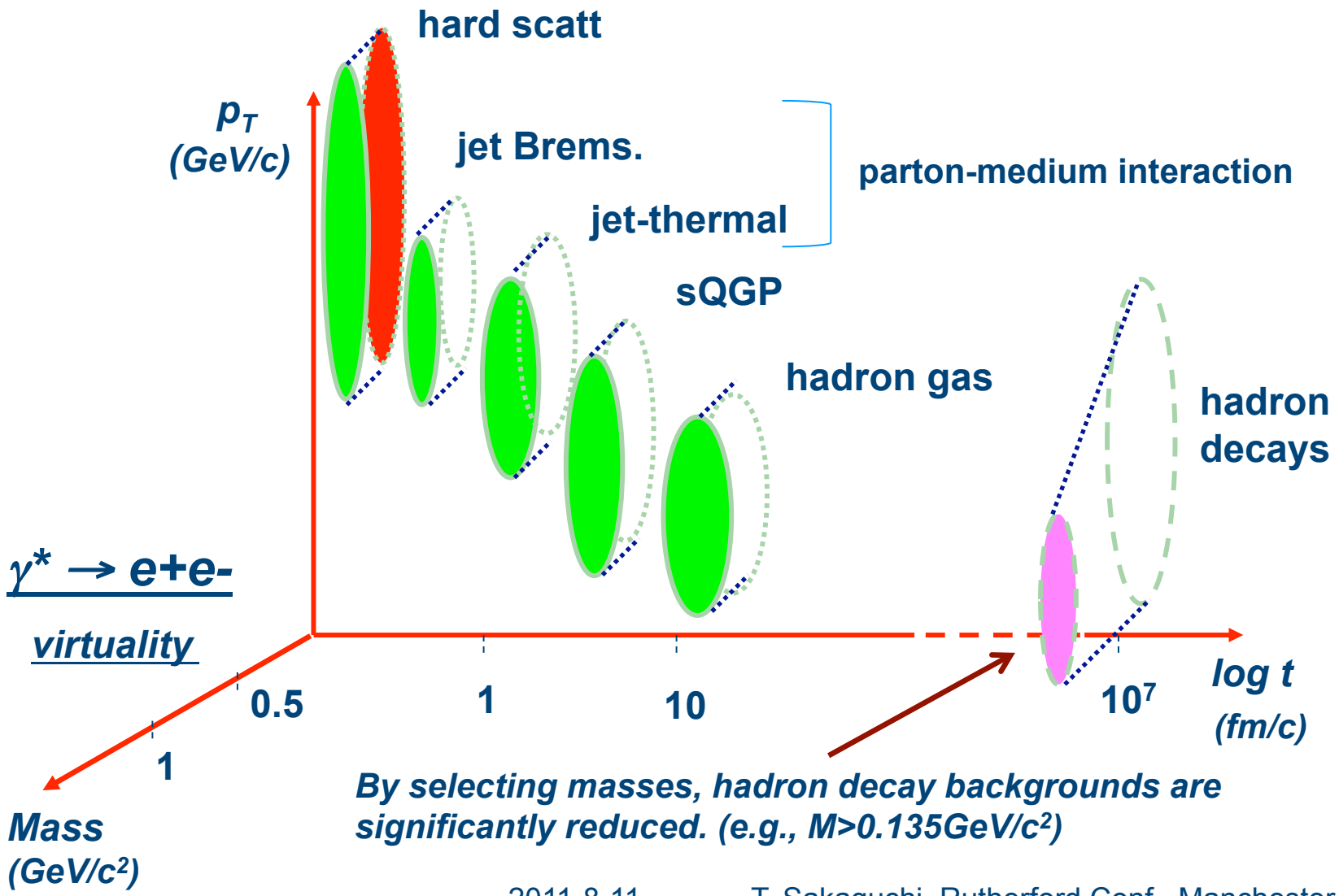


Possible sources of photons

See e.g., Turbide, Gale, Jeon and Moore, PRC 72, 014906 (2005)

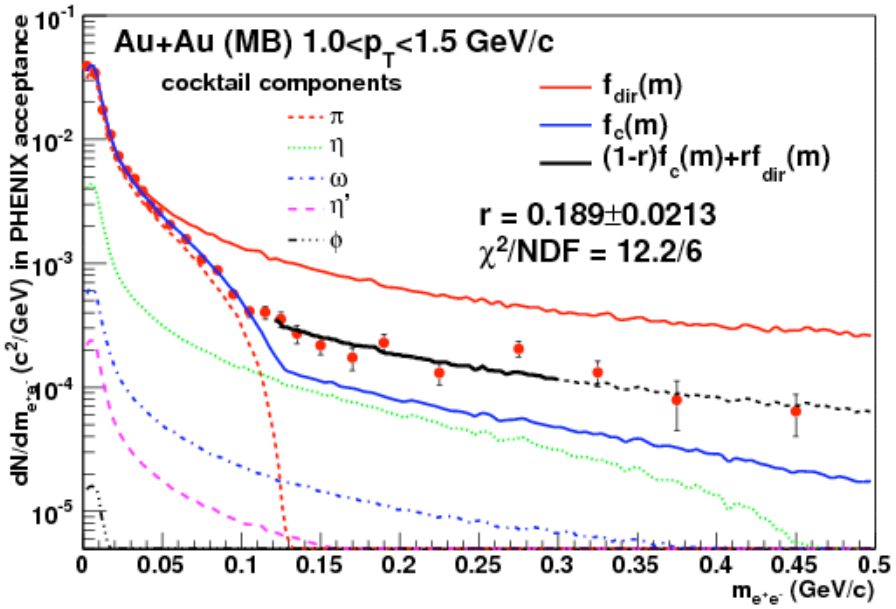


Possible sources of photons



By selecting masses, hadron decay backgrounds are significantly reduced. (e.g., M>0.135GeV/c^2)

Low p_T photons with very small mass

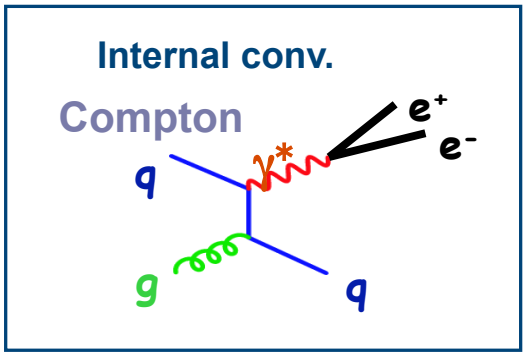


One parameter fit: $(1-r)f_c + r\, f_d$
f_c: cocktail calc., f_d: direct photon calc.

$$\frac{1}{N_\gamma}\frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}\left|F(m_{ee}^2)\right|^2\left(1-\frac{m_{ee}^2}{M^2}\right)^3$$

$$r = \frac{\gamma^*_{dir}(m>0.15)}{\gamma^*_{inc}(m>0.15)} \propto \frac{\gamma^*_{dir}(m\approx 0)}{\gamma^*_{inc}(m\approx 0)} = \frac{\gamma_{dir}}{\gamma_{inc}}$$

- Focus on the mass region where π^0 contribution dies out
- For $M \ll p_T$ and $M<300\,MeV/c^2$
  - $q\bar{q} \rightarrow \gamma^*$ contribution is small
  - Mainly from internal conversion of photons
- Can be converted to real photon yield using Kroll-Wada formula
  - Known as the formula for Dalitz decay spectra

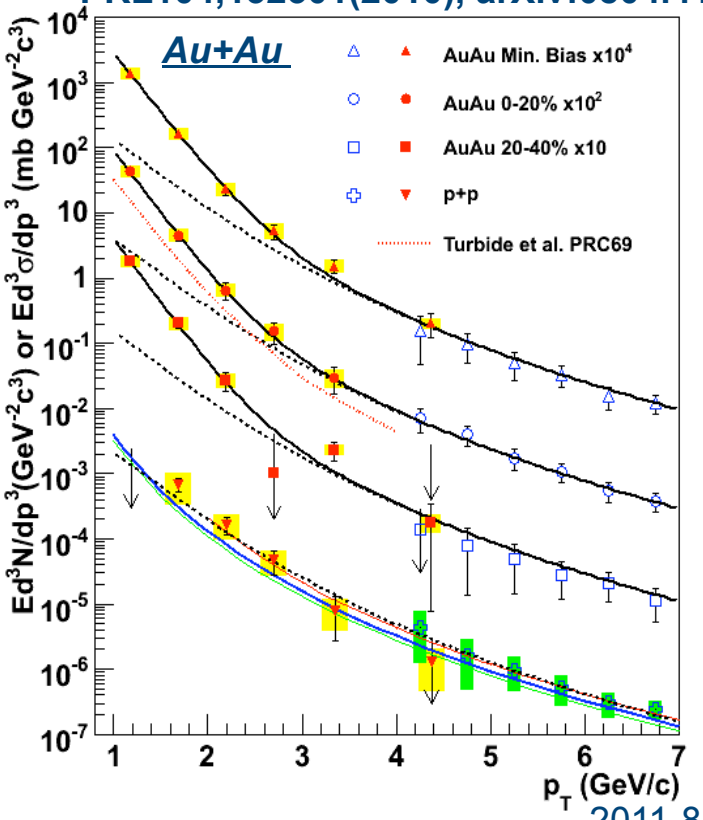


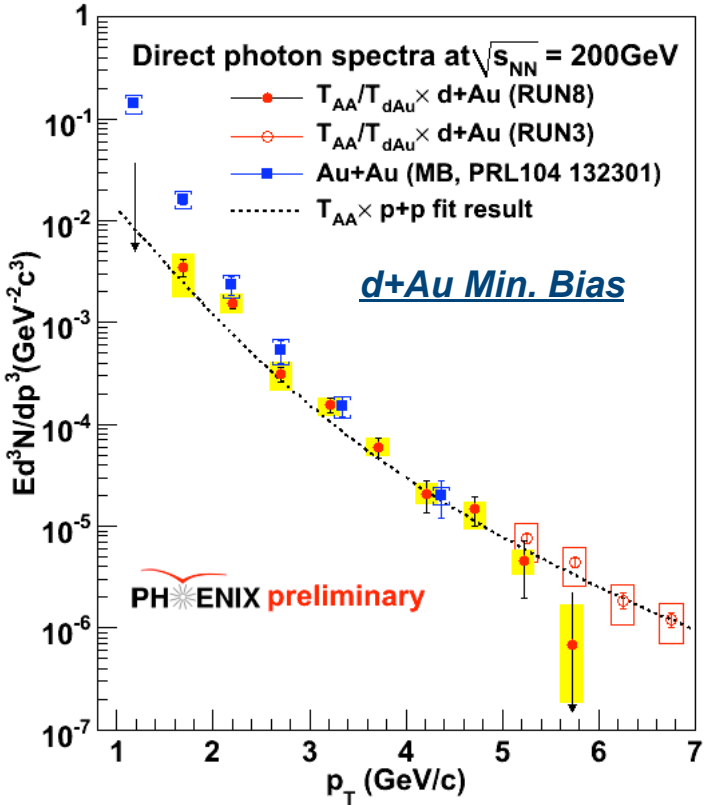
PRL**104**,132301(2010), arXiv:0804.4168

Low p_T photons in Au+Au (thermal?)

- Inclusive photon × $\gamma_{dir}/\gamma_{inc}$
- Fitted the spectra with p+p fit + exponential function
  - **T_{ave} = 221 ± 19^{stat} ± 19^{syst} MeV (Minimum Bias)**
- Nuclear effect measured in d+Au does not explain the photons in Au+Au

PRL104,132301(2010), arXiv:0804.4168

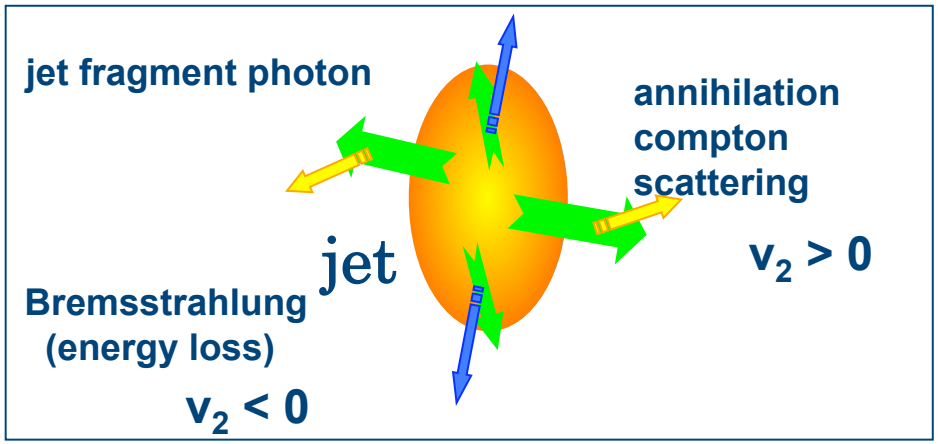


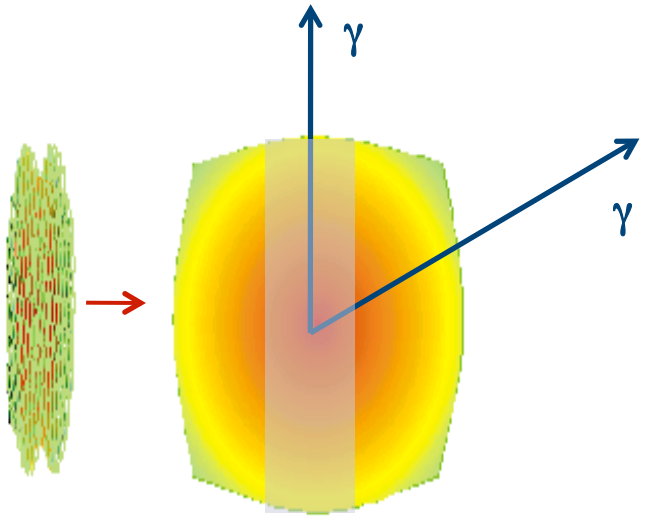


Profiling collision systems using photons

- Depending the process of photon production, path length dependence of direct photon yield varies
  - v_2 of the direct photons will become a source detector
  - Late thermalization gives larger v_2

- Once the path length dependence has been fixed, system expansion scenario can be studied by looking at photons at different rapidities.
  - e.g. PRC71 (2005) 064905



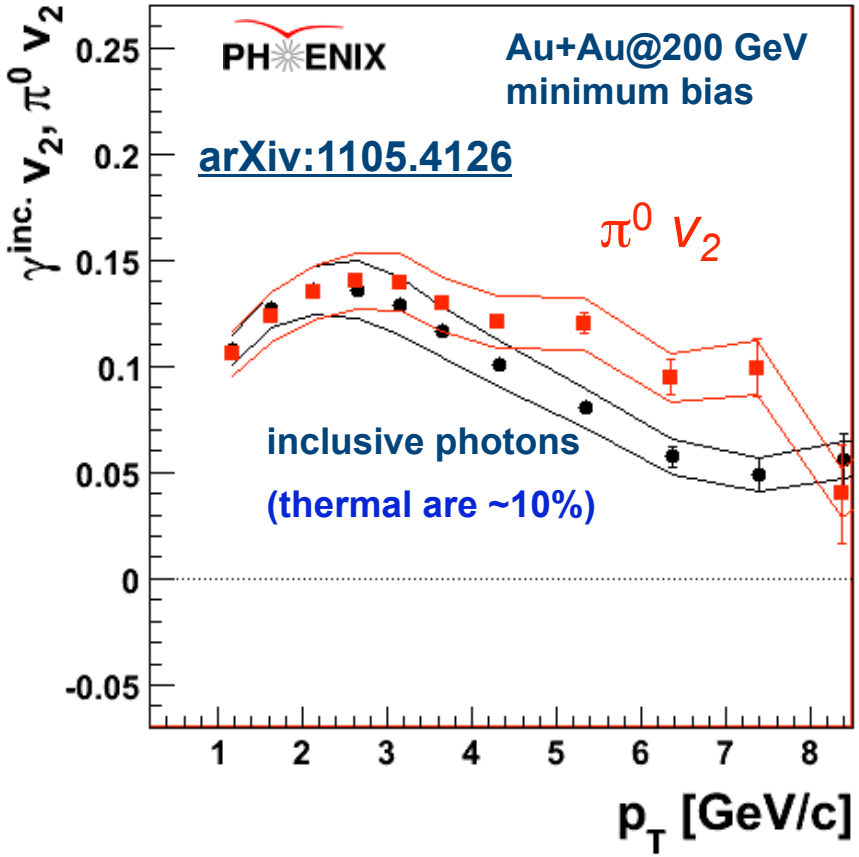


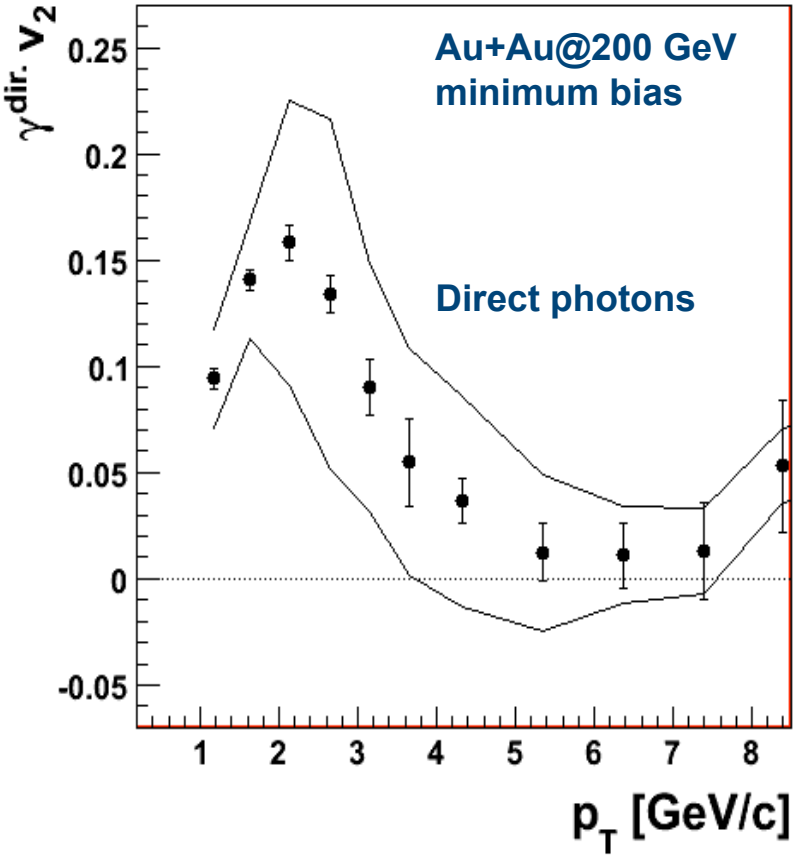
For prompt photons: v_2~0

Low p_T photon flow

- Hadron decay photon v_2 subtracted from inclusive photon v_2.

$$v_2(dir.\gamma) = \frac{R \times v_2(incl.\gamma) - v_2(bkgd.\gamma)}{R-1} \qquad R = \frac{N^{inc.photon}}{N^{BG\_photon}}$$

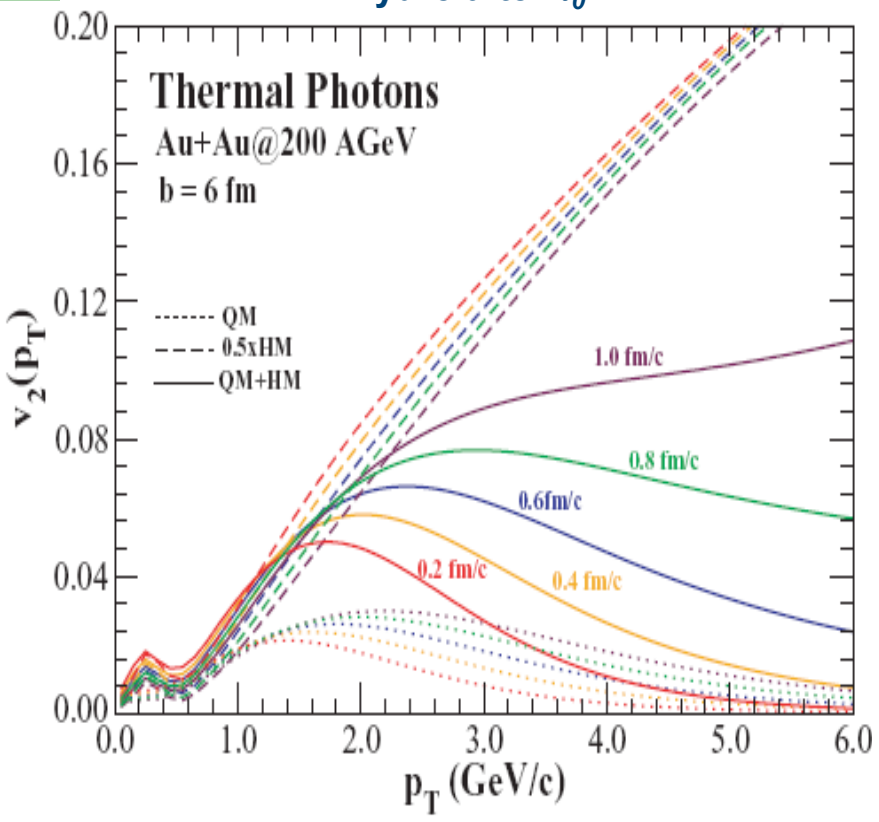




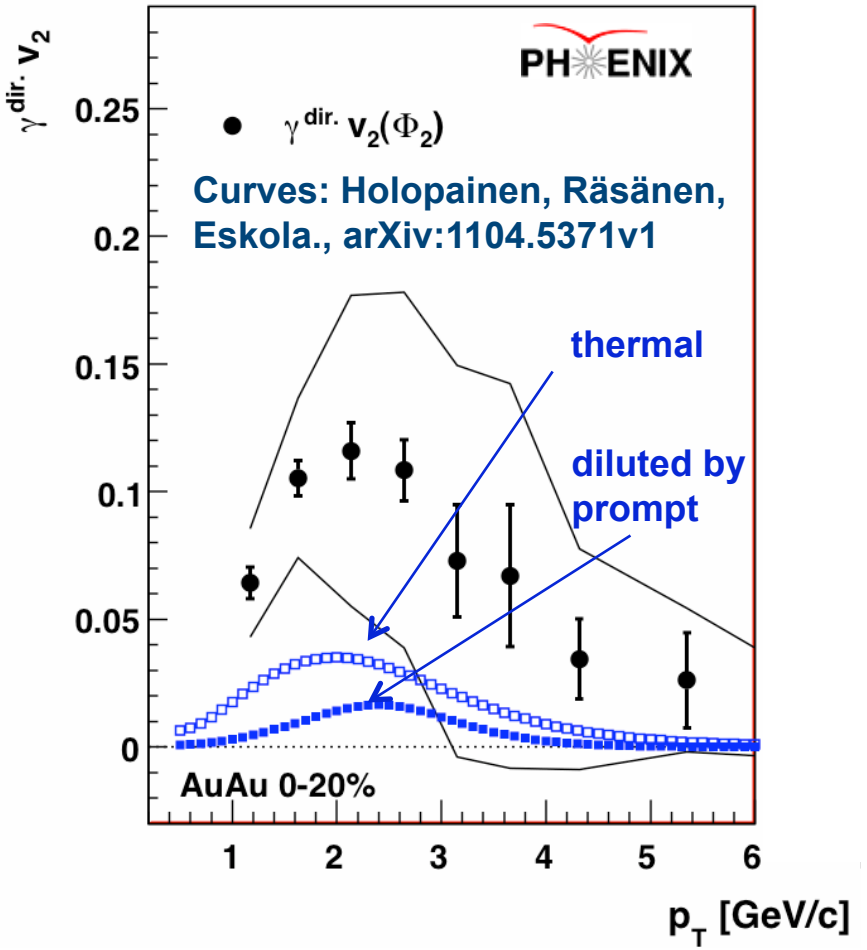
What we learn from model comparison

- Large photon flow is not explained by models

Hydro after τ_0



Chatterjee, Srivastava PRC79, 021901 (2009)



T. Sakaguchi, Rutherford Conf., Manchester, UK

Summary

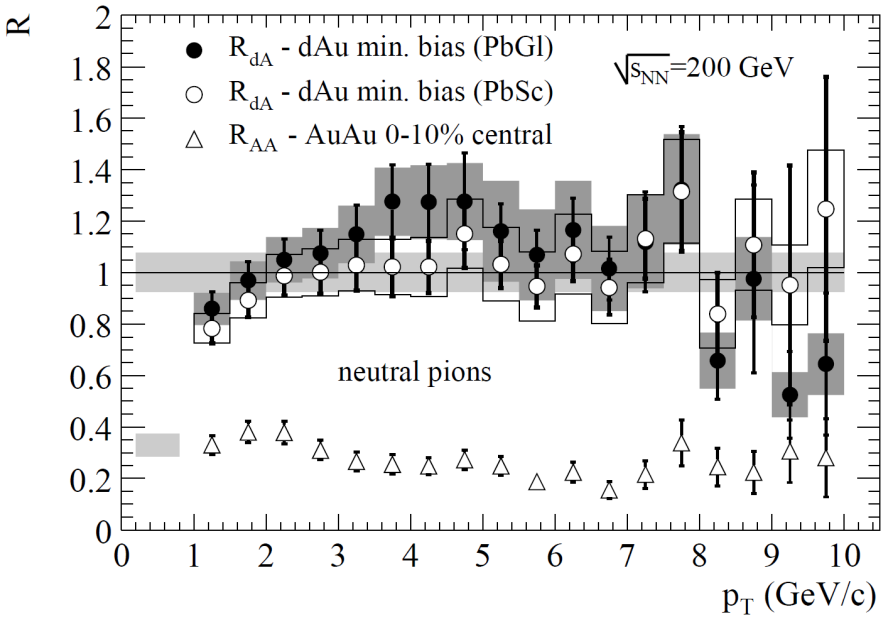
- Direct photons are a power tool to investigate the collision dynamics
  - From initial state till the freezeout of the system
- Hard scattering photons have been measured in nucleus collisions for the first time
- Low p_T photons show thermal characteristics (exponential slope)
- Direct photon v_2 has been measured for the first time
  - Powerful source detector
  - Unexpectedly large flow was seen. Not explainable by models

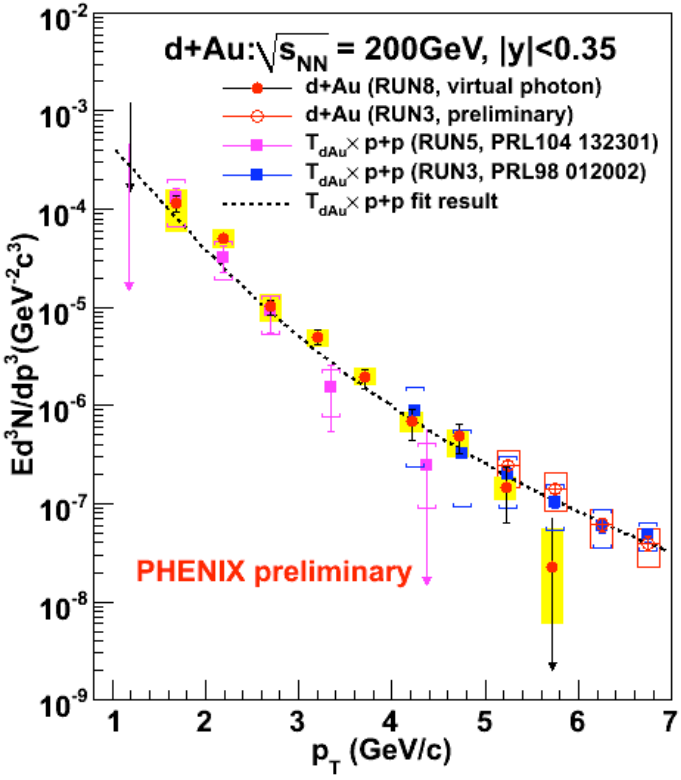
Backup

Initial kT or recombination?

- Recombination model claims that the Cronin effect in hadron production is built up by recombination (e.g. R. Hwa, Eur.Phys.J.C43:233(2005))
  - Cronin effect in direct photon production should be much smaller than one in pi0
- Within quoted errors, the effect is same for pi0 and photon production
  - Recombination model needs improvement

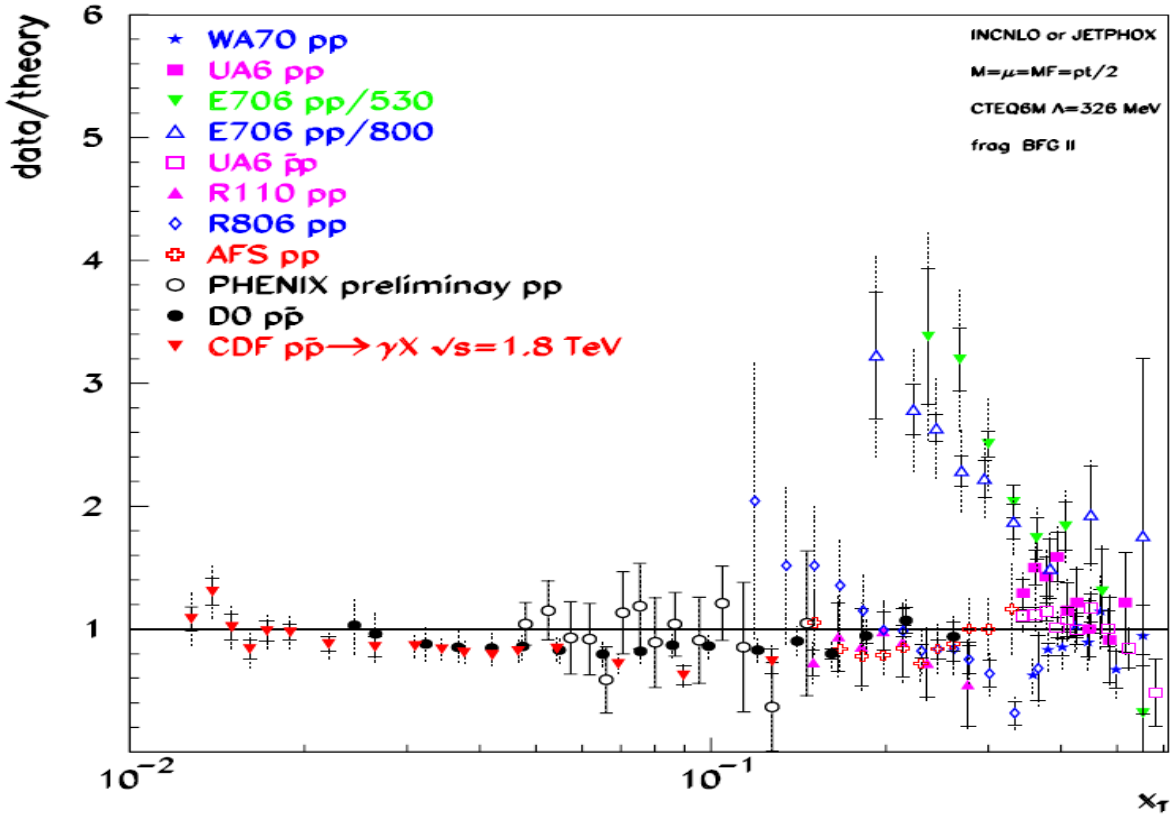
Pi0 RAA in d+Au at 200GeV. PRL91, 072303 (2003)





High pT γ_{dir} in p+p – (p)QCD test

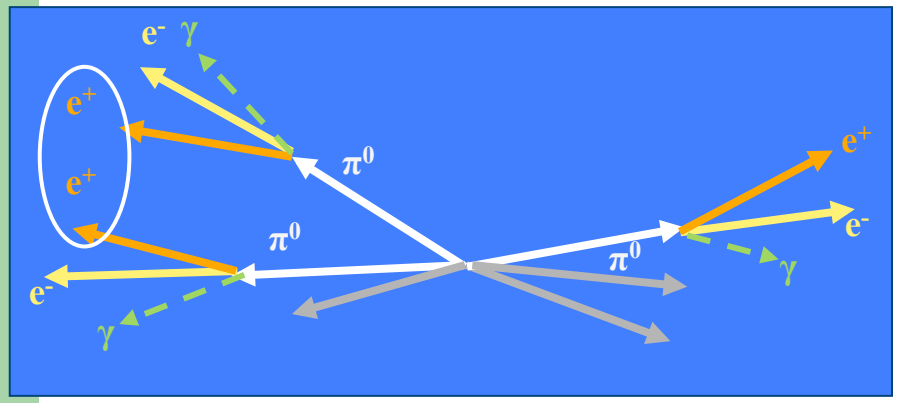
- NLO pQCD calculation of γ_{dir} yield is tested with p+p collisions
- The calculation works very well

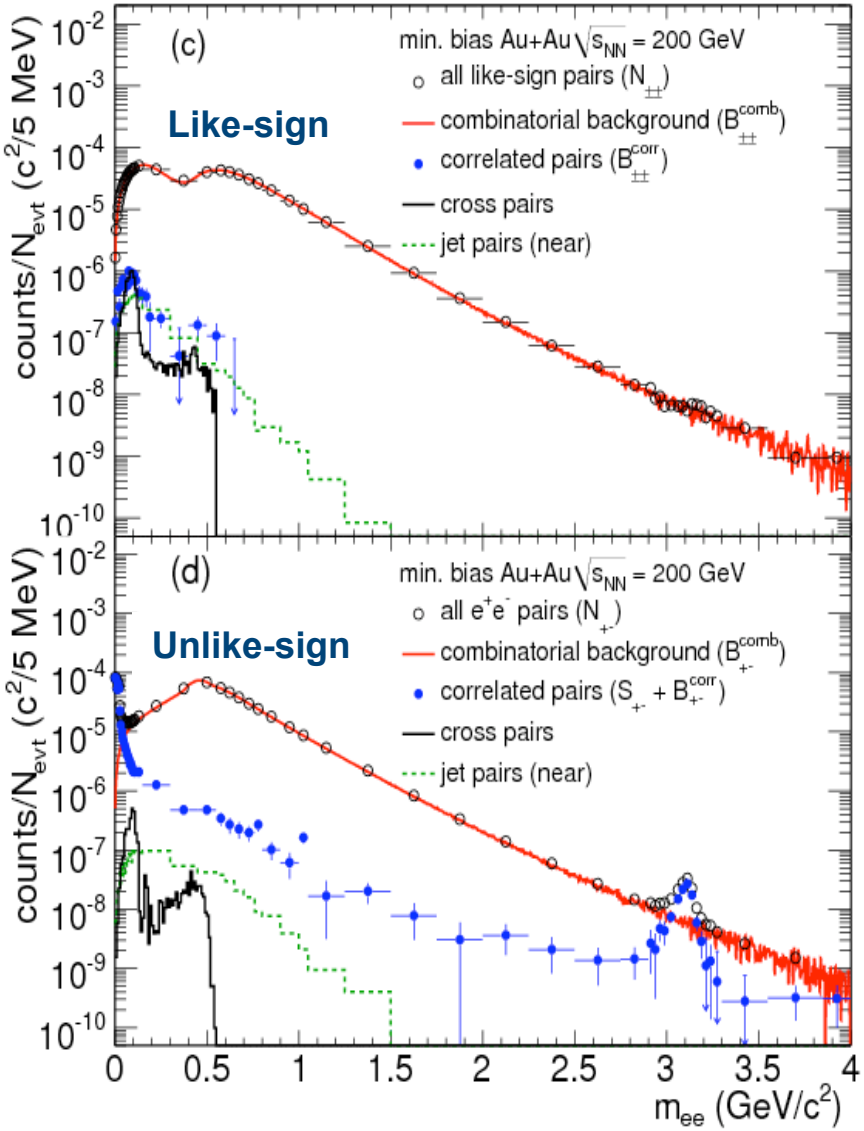


Aurenche et al., PRD73, 094007(2007)

Analysis

- Reconstruct Mass and pT of e+e-
  - Identify and reject conversion photons in beam pipe, using angular correlation of electron pairs
- Subtract combinatorial background
  - Background checked by like-sign dist.
- Apply efficiency correction
- Subtract additional correlated background:
  - Back-to-back jet contribution
  - Determine amount in like-sign dist, and apply to unlike-sign dist.
- Compare with known hadronic sources

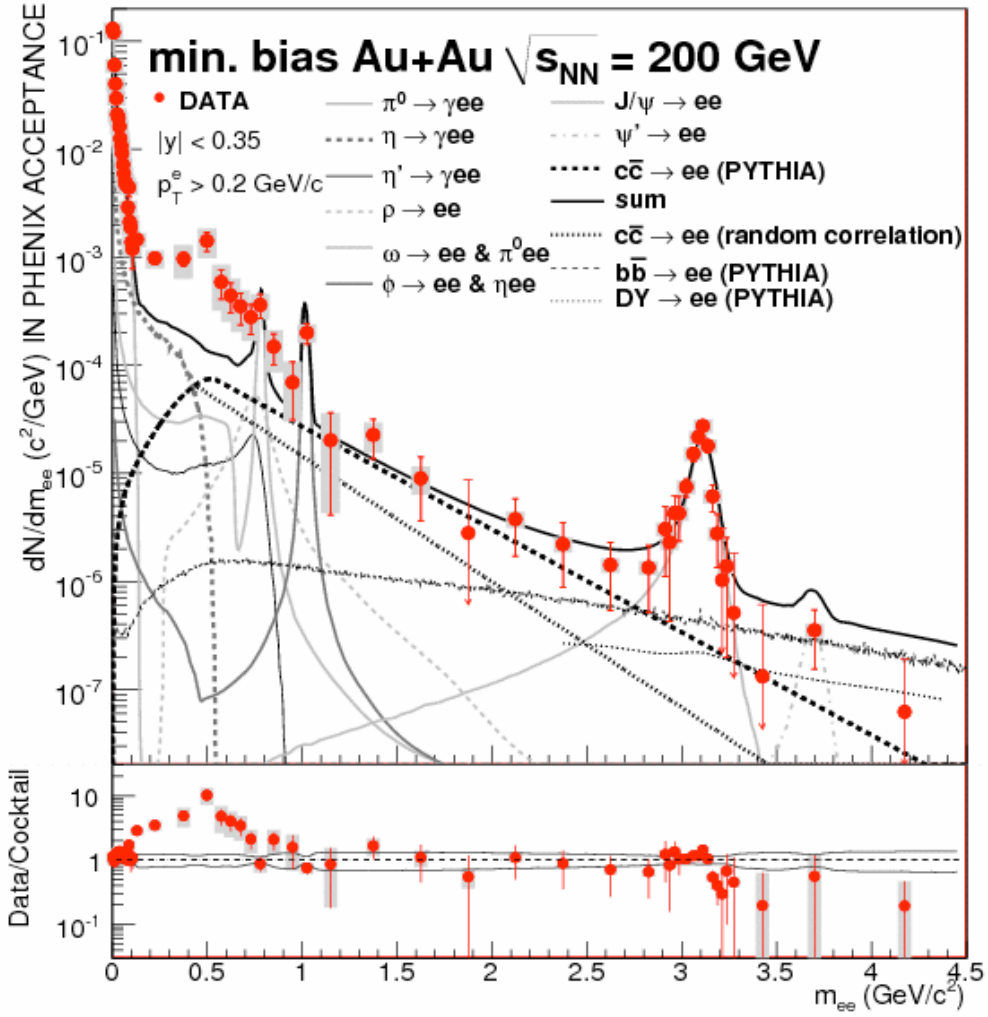




PRC**81**, 034911(2010), arXiv:0912.0244

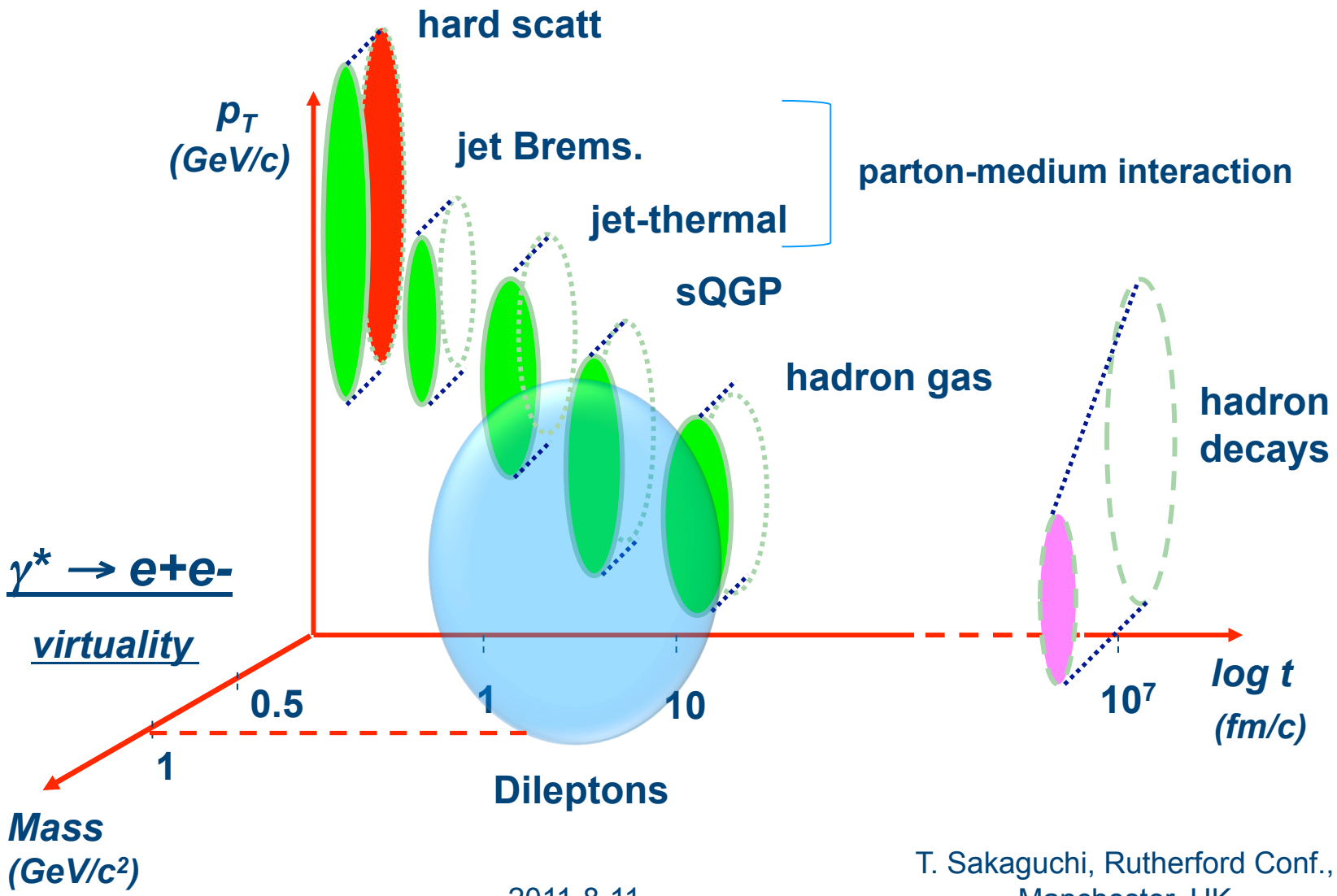
Outcome from Au+Au collisions

- Comparing with various sources of electron pairs
- Cocktail of the sources are calculated based on π^0/η spectra measured in PHENIX
- Huge excess over cocktail calculation is seen in 0.2-0.8GeV/c^2

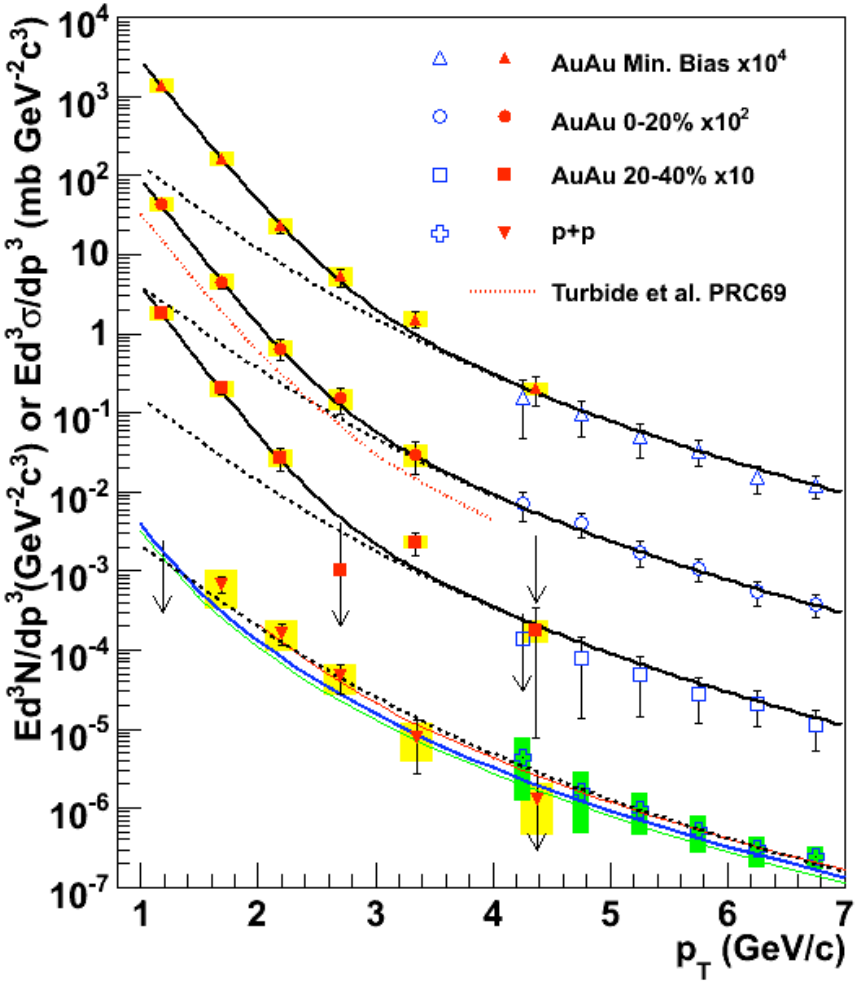


PRC**81**, 034911(2010), arXiv:0912.0244

Sources of electro-magnetic probes



Direct photons through dileptons



- Inclusive photon × $\gamma_{dir}/\gamma_{inc}$
- Fitted the spectra with p+p fit + exponential function
- Barely dependent of centrality

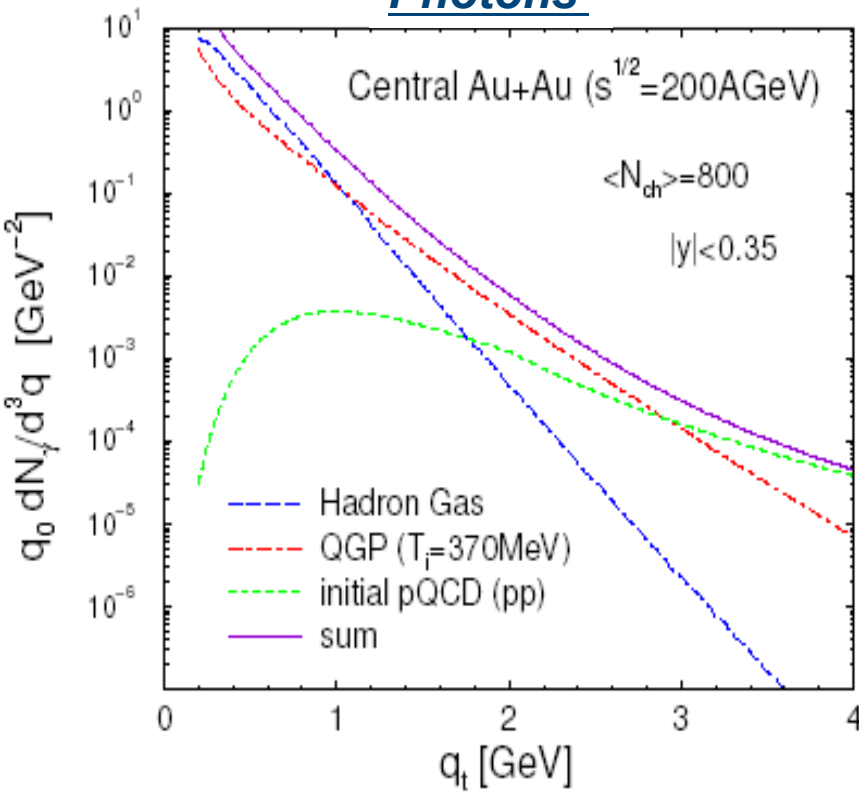
Cent	dN/dy (pT>1GeV)	Slope (MeV)	χ^2/ DOF
0-20%	1.50±0.23± 0.35	221±19± 19	4.7/4
20-40%	0.65±0.08± 0.15	217±18± 16	5.0/3
MinBias	0.49±0.05± 0.11	233±14± 19	3.2/4

PRL**104**,132301(2010), arXiv:0804.4168

Theory prediction on dilepton/photons

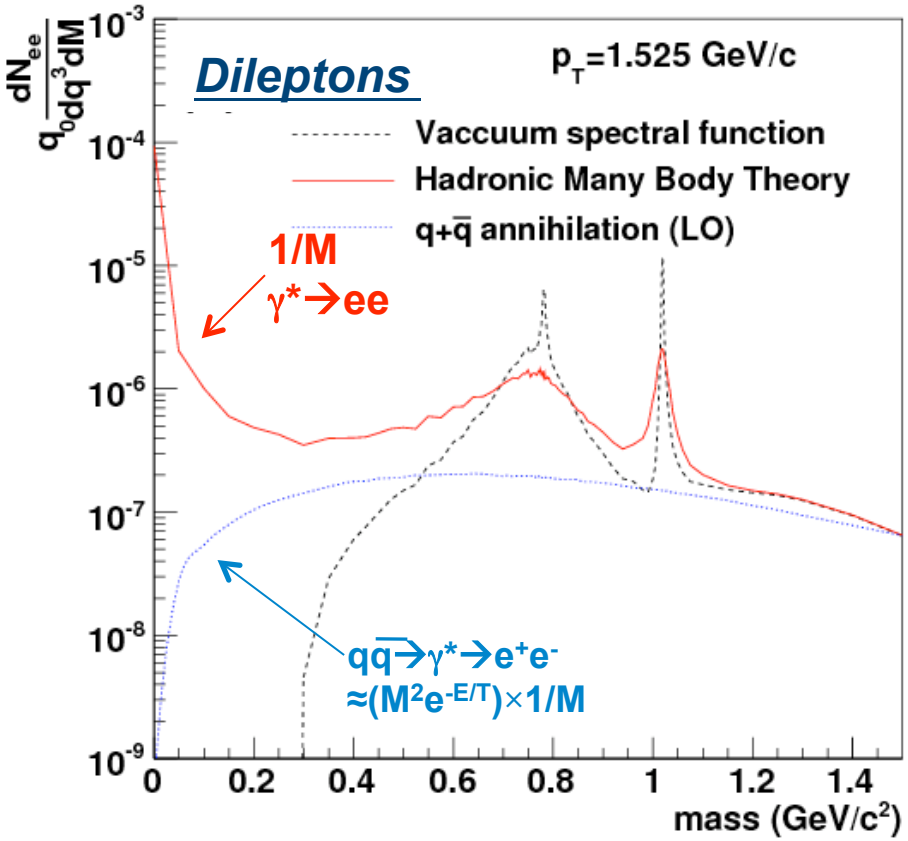
- Similar source are seen in both dileptons and photons
- Internal conversion of photons is not shown in dilepton calculation

Photons



PRC 69(2004)014903

Dileptons



Ralf Rapp, priv. comm.

Dilepton measurement in PHENIX

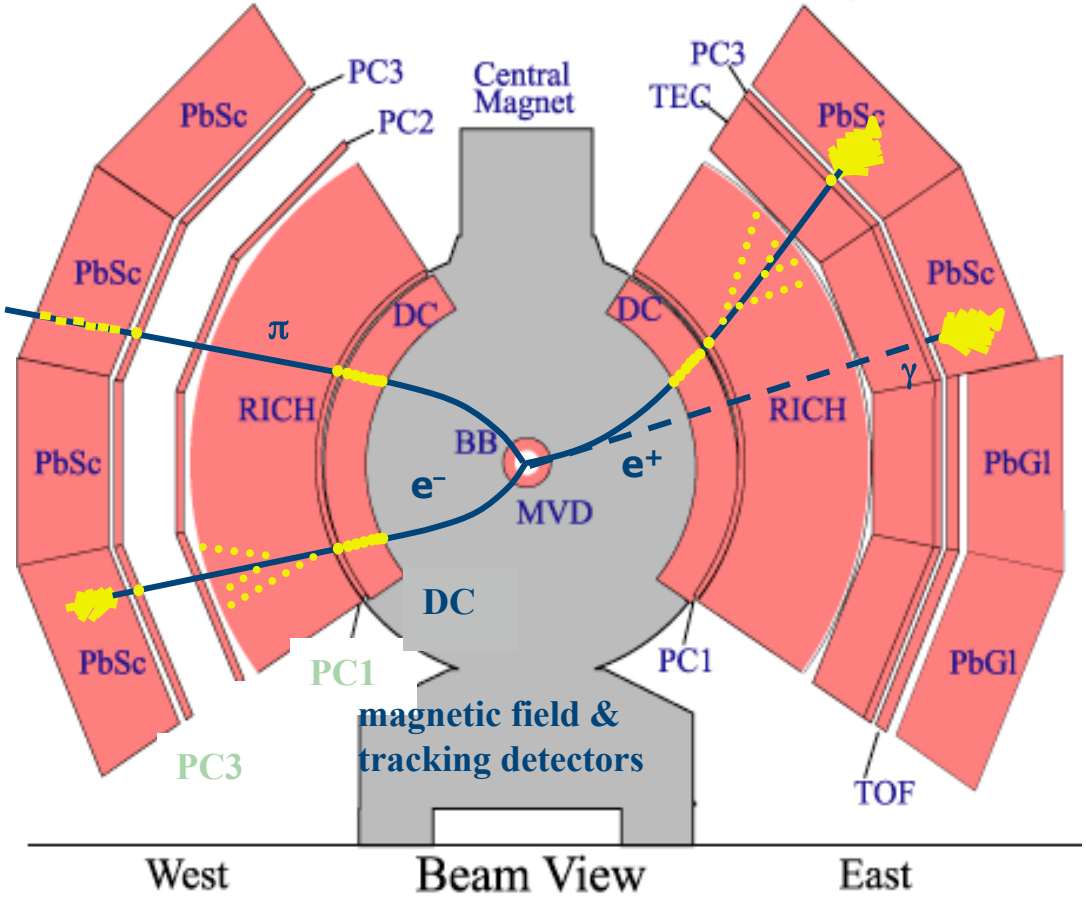
Designed to measure rare probes:

Au-Au & p-p spin

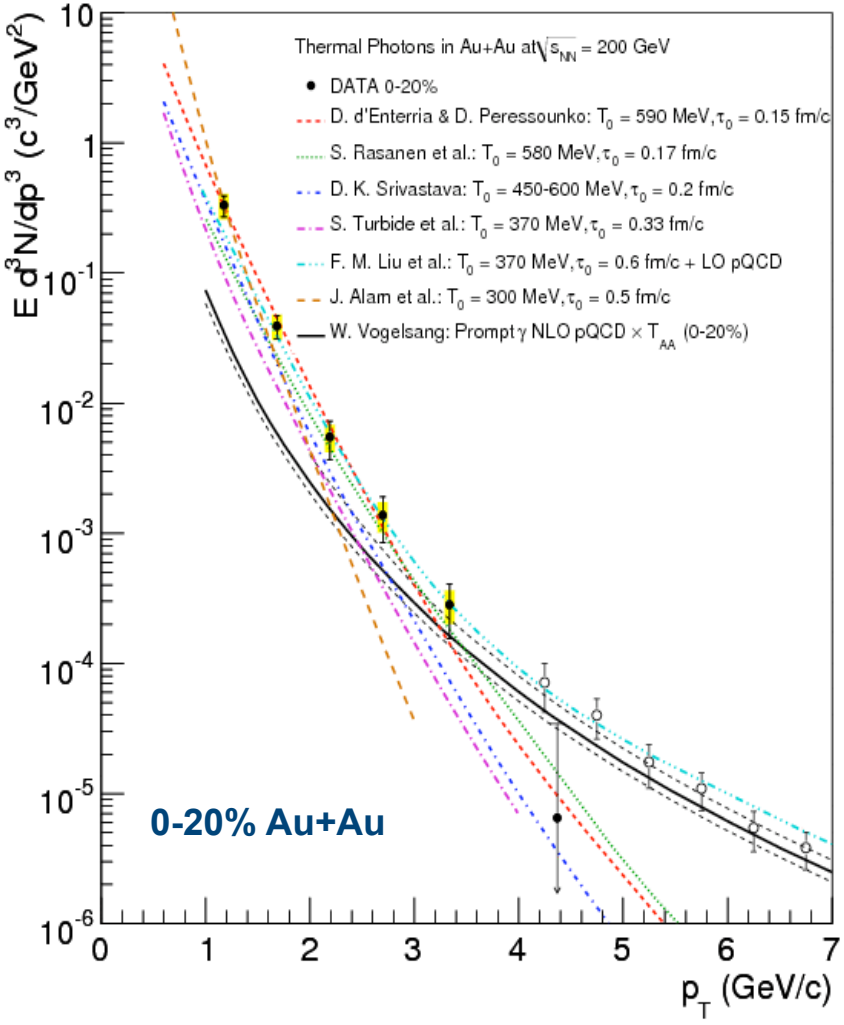
+ high rate capability & granularity
+ good mass resolution and particle ID
- limited acceptance

- 2 central arms:

  electrons, photons, hadrons
  - charmonium J/ψ, ψ' -> e^+e^-
  - vector meson r, w, ϕ -> e^+e^-
  - high p_T p^o, p^+, p^-
  - direct photons
  - open charm
  - hadron physics



Calculations reasonably agree with data



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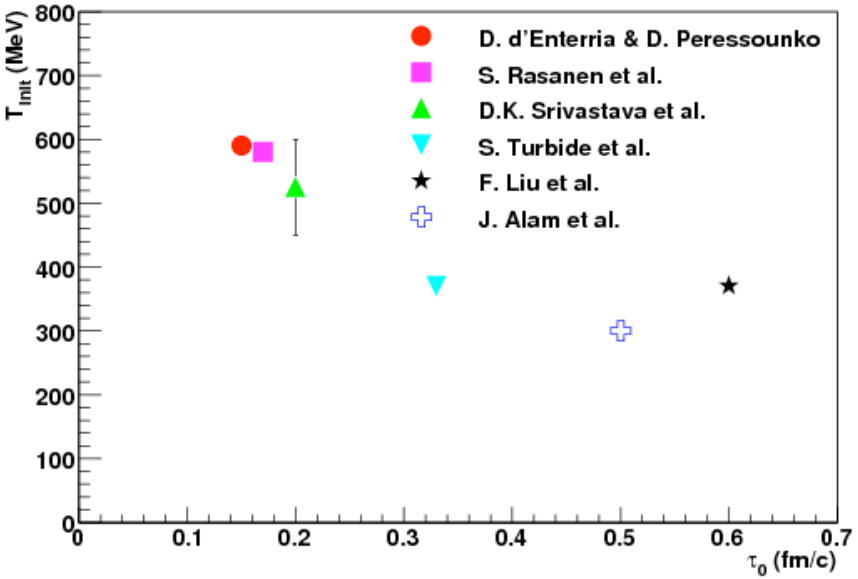
- Factors of two to be worked on ..
- Correlation between T and τ_0



T_{ini} = 300 to 600 MeV
τ_0 = 0.15 to 0.5 fm/c

Direct γ to inclusive γ ratios

- Shown are in p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}}$=200GeV
- Lines are NLO pQCD calculation with mass scales (pT=0.5, 1.0, 2.0)
- Excess in min. bias Au+Au is much higher than that in d+Au